Arctic Mixed Layer Dynamics

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LONG-TERM GOAL

Our long term goal is to understand the dynamic and thermodynamic processes causing changes in the velocity and density structure of the upper Arctic Ocean. For example we seek to understand the heat and mass balance of the mixed layer. In light of recent changes in the upper ocean structure, our long-term goals are shifting partly toward a better understanding of large scale changes and their connection to global scale forcing.

OBJECTIVES

Our long term goals have taken on new significance considering recent changes in the Arctic Ocean hydrography. The results of several expeditions in the 1990's indicate the upper Arctic Ocean is increasingly dominated by the Atlantic Water. The salinity of the upper 200 m of the Makarov Basin has increased by over 2.5 o/oo. A warm core of Atlantic Water now lies over the Lomonosov Ridge and the halocline is thinning. Two of our immediate objectives have been to determine if the change is a significant departure from the historical climatology, and what is the role of upper ocean processes in the change. These remain central to this work, but as our studies have progressed we have found the scope of the Arctic change is much greater than previously thought, involving atmospheric circulation changes over most of the northern hemisphere and effects over land as well as the Arctic Ocean. Consequently, we wish to explore the scope of the change and develop a community wide program to examine it.

APPROACH

We have developed and use a variety of techniques in our analyses. Standard hydrographic analysis techniques are used with most historical data. The special analysis of hydrographic buoy data takes advantage of the buoy cable motion to improve vertical resolution. We are using data from the US-Russian Joint Oceanographic Atlases both to provide bench mark data and as an aid to interpolating other data to a common reference position. We have a subcontract with Vladimir Pavlov at the Arctic and Antarctic Research Institute in St. Petersburg, Russia to model the influence of Russian shelf waters on the basin and to supply additional data from Russian archives. We have also obtained additional Russian data from Leo Timokhov, also at AARI, under an NSF-funded subcontract.

WORK COMPLETED

We have been working to organize a multi-disciplinary, multi-agency study involving measurements, analysis, and modeling to understand the large changes currently under way. In prior years we circulated an Open Letter Describing a Program for a Study of Arctic Change and proposed to

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the National Science Foundation to hold a workshop on the subject. The workshop was held in November of 1997. With funding from NSF and this grant, we assembled material from the meeting and subsequent sources for a report on observations of the Arctic Change. We have examined the changes seen in recent years in comparison with interdecadal and intradecadal statistics of variability that are included in the EWG (1997, 1998) Joint US-Russian Atlases, and demonstrated the significance of the recent changes. We have also examined early data returned from the SHEBA deployment phase and found a marked freshening of the Beaufort Sea mixed layer. With SHEBA colleagues we published a paper comparing this observation to AIDJEX in the context of Arctic Change. We co-authored one multidisciplinary review paper (Serreze et al., 1998) on observations of change and are finishing another that synthesizes recent observations of change in the Arctic Ocean and in the Northern Hemisphere atmospheric circulation (Morison, Aagaard, and Steele, 1998).

RESULTS

Several key facts were known at the beginning of this contract. Numerous observations over the last several years have indicated the Arctic is undergoing a significant change. The hydrography of the Arctic Ocean has shifted. Typically the eastern Arctic Ocean on the European side of the Lomonosov Ridge is dominated by water with an Atlantic origin. This water underlies a cold halocline of varying thickness that isolates the warmer Atlantic water from the sea ice and surface mixed layer. The western Arctic Ocean on the North American side of the Lomonosov Ridge is characterized by an added layer of water from the Pacific immediately below the surface mixed layer. Data collected during several cruises from 1991 to 1995 indicate that in the 1990's the boundary between these eastern and western halocline types shifted from roughly paralleling the Lomonosov Ridge to being nearly aligned with the Alpha and Mendeleyev ridges (ex Morison, Steele, and Andersen, 1998). The change has resulted in increased surface salinity in the Makarov basin. The Atlantic Water temperature has also increased. Comparison of the temperature measured during cruises in the 1990's and temperatures from the atlas reveal a new warm core of Atlantic Water over the Lomonosov Ridge. The maximum temperature is over 1°C warmer than in the past. Furthermore the Atlantic Water is shallower than in the past so the temperature is over 2° greater at 200 m. A less intense warm core appears over the Mendeleyev Ridge and there is a general warming in the Makarov Basin centered at around a depth of 200 m. These observations reinforce the idea that Atlantic Water has intruded across the whole Makarov Basin. Atmospheric pressure fields and ice drift data show the patterns of atmospheric pressure and ice drift for the early 90's were shifted counterclockwise 40°-60° from earlier patterns.

Decadal statistics from the atlas indicate this change is greater than the normal variability. We have compared the increased salinity of the Makarov Basin to the interdecadal variability found in the EWG (1997) Atlas. Historically some shifting of the front has occurred, but the magnitude of the variation amongst the 1950's, 1960's, 1970's, and 1980's was much less than the shift in the 1990's. By examining the data for the 1970's, the decade with the most data in the atlas, we have found the area of greatest variability in the past is the same as the area where we see the change now. However, while the observed change is 2.5 o/oo, the rms variation was less than a fifth of that in the 1970's. Similarly we find the recent temperature maximum is very much greater than the maximum temperatures observed between 1950 and 1990, The rms temperature variation is a maximum over the Lomonosov Ridge and is high in the regions where the change has occurred. This suggests these areas have always been areas of maximum variability, but as with salinity, the rms variation was less than a fifth of the observed changes. In other words the ocean changes have occurred in the usual areas of variability, but they are much larger than those measured in the past.

Although the changes described so far have been observed in the Eurasian Basin and Makarov Basin, there have been interesting changes in the Beaufort Sea as well. In McPhee et al. (1998) we report that during the SHEBA (Surface Heat Budget of the Arctic Ocean) deployment phase in October 1997 multiyear ice near the center of the Beaufort Gyre was anomalously thin. The upper ocean was also both warmer (relative to freezing) and less saline in 1997 than during the 1975-76 Arctic Ice Dynamics Experiment (AIDJEX). The estimated decrease in salinity during the summer of 1997 was 3 times the decrease observed in the same place during the summer of 1975. This suggests the amount of ice melt was greater, in agreement with much lower observed ice thickness. Subsequent to publication of McPhee et al. (1998), we examined various data sources, but mainly the EWG (1997, 1998) atlases, to learn the history of surface salinity in the Beaufort Sea. Figure 1 shows the salinity between 2 and 20 m at the site of the SHEBA deployment measured by various means since 1963. Data are from drifting buoys and, AIDJEX, the ice island T-3, several Russian North Pole stations (Timokhov, personal communication) and two SCICEX submarine cruises. Data for late spring and early fall are shown; the separation of the two curves indicates the amount of summer melt water. The figure illustrates that the summer melting at AIDJEX was anomalously low. Indeed the summer of 1975 was a bad ice year in the Beaufort Sea. However, the figure supports the general conclusions of McPhee et al. (1998). The net change in Spring salinity between 1963 and 1997 is 0.5 o/oo and the decrease in early Fall salinity is nearly 1.5 o/oo. The average salinity has decreased and the summer freshening has increased especially in the last 10 years.

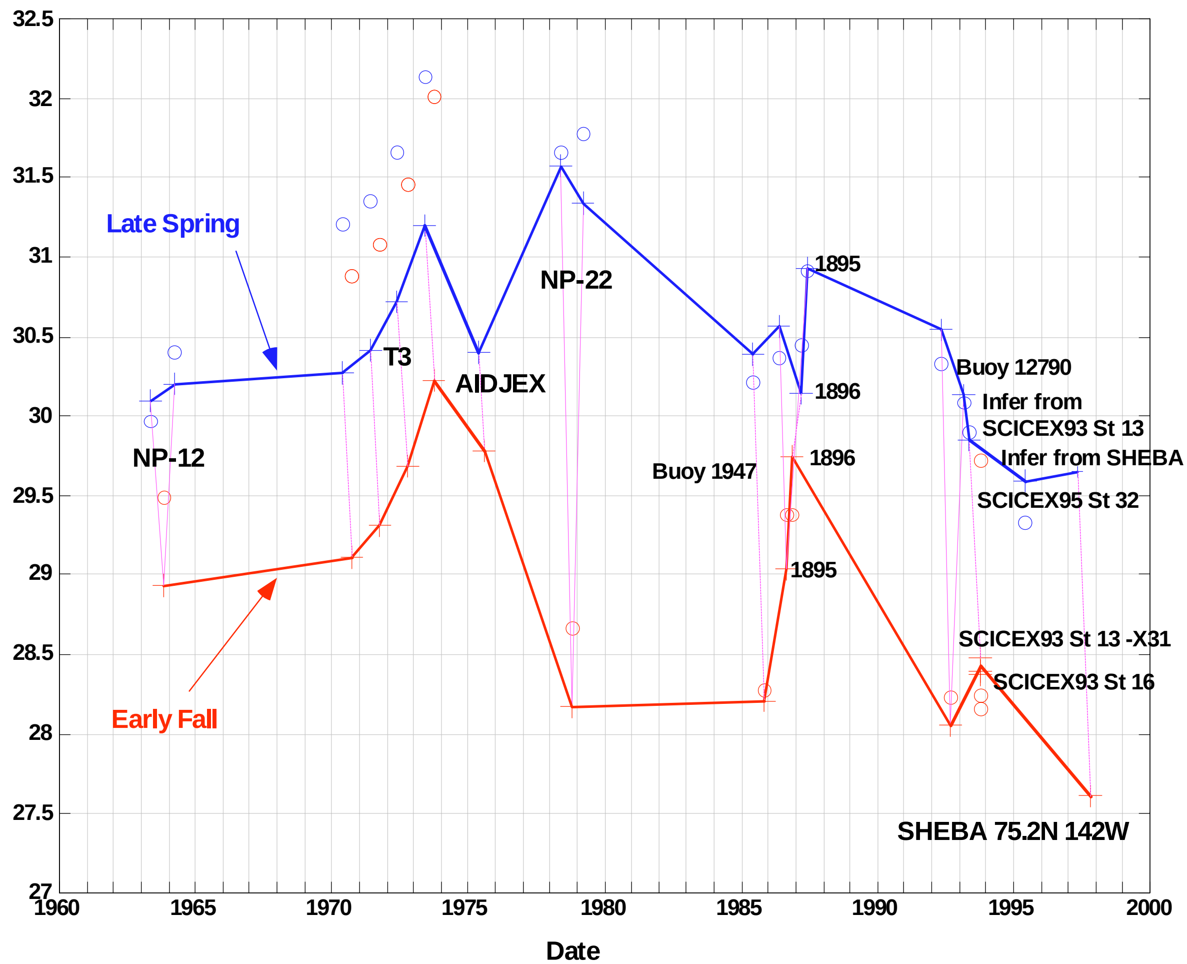

Figure 1. Beaufort Sea 5-20 m average salinities from North Pole 12, 22, and 31 (courtesy Leo Timokhov), T-3, AIDJEX, Hydrographic buoys 1947, 1895, 1896, 12790, SCICEX '93, SCICEX '95 and SHEBA. The circles indicate original data and the plux signs are the data interpolated to the position of the SHEBA data using the grided fields of the EWG (1997, 1998) atlases as a guide. The upper line is drawn through data from late spring and the lower line is through data from the late summer or early autumn.

A more comprehensive view of the Arctic Change is given by considering the leading empirical orthogonal function (EOF) of sea-level pressure for the Northern Hemisphere. In work that was being completed at the time of the Arctic Change Workshop, Thompson and Wallace (1998), show that this EOF is more strongly coupled to surface air temperature variations over the Eurasian continent than the North Atlantic Oscillation (NAO). The shape of this EOF resembles the NAO, but its strong negative lobe is more nearly centered over the North Pole. It has strong positive lobes over the North Pacific and North Atlantic. The time variation of the leading EOF is called the Arctic Oscillation (AO) by Thompson and Wallace (1998) and shows a strong increase in the last 10 to 20 years. The AO is associated with low pressure over the Arctic Ocean, so that the particularly rapid increase in Arctic Oscillation (AO) index after the late 1980s agrees with the results of Walsh et al. (1996). This corresponds to an intensified cyclonic vortex centered on the North Pole, and because of the position of the high pressure lobes, produces advection of warm air over Northern Europe. The results agree with the results of Chapman and Walsh (1993) and Martin et al. (1997) that surface air temperatures in the

Arctic have been increasing. Thompson and Wallace (1998) also show the change in the atmosphere extends from the top of the atmosphere to the surface and postulate that it represents a fundamental mode of oscillation of the atmosphere. To produce the barotropic structure requires a cooling in the stratosphere and a warming of the lower troposphere in a manner compatible with scenarios of greenhouse warming.

In an invited paper for the Arctic Seas Symposium (October 21-24, 1998, Mystic, CN) we review these observations and relate the results of Thompson and Wallace (1998) to the changes observed in the Arctic Ocean. In this paper we suggest the following chain of events explaining the observed characteristics of the Arctic change. The advection of warm air around the southern tip of Greenland brings warm air to the Greenland Sea and Russian Arctic. Warmer air over the Greenland Sea reduces the cooling of Atlantic Water in the Greenland Sea. This allows the Atlantic Water to enter the Arctic Ocean at a higher temperature and results in elevated water temperatures in the basin. Warm air advection has also increased the surface air temperature over northern Russia and thereby caused thawing of permafrost. The strengthening of the polar vortex has resulted in lower surface pressure and a consequent weakening and distortion of the Beaufort Gyre. It has increased the cyclonicity of the ocean circulation especially in the Makarov Basin area and shifted the front and transpolar drift counterclockwise. The change in circulation may also account for the decreased ice cover on the Siberian shelves described by Maslanik et al. (1996). The weaker Beaufort High decreases ice convergence in the Beaufort Sea and results in more open water, lower albedo, more summer heat input to the upper ocean, and more sea ice melting. Combined with possible fresh water from Russian shelves, this freshens the upper Beaufort Sea. The added cyclonic motion in the basin may drive more relatively fresh surface water from the Western Arctic through the west side of Fram Strait and thereby increase the stratification of the Greenland Sea. This may contribute to the relative absence of deep convection in recent years.

IMPACT/APPLICATION

It is of utmost importance that the changes in the Arctic Ocean be studied in detail. They may represent a decadal-scale change or the start of a longer term shift. In either case examining the evolution of the changes over time will likely tell us much about the interplay of the Arctic with the rest of the globe. The Study of Arctic Change has relevance to the Navy because it involves significant changes in the upper ocean and coastal areas. These are areas important for naval operations, and it is here that oceanographic conditions are most likely to be different in the future than when examined heavily in the 1980s by the Navy. The Arctic change may be even more important for its effect on the northern sea route. Other nations, notably Japan and Russia are examining the potential of the northern sea route for trade. If the Arctic change affects navigability of the northern sea route, this may change shipping patterns between Asia and northern Europe and the strategic significance of the Arctic Ocean.

TRANSITIONS

See above.

REFERENCES

Chapman, W. L., and J. E. Walsh, 1993, Recent variations of sea ice and air temperature in high latitudes, *Bull. Amer. Meterol. Soc.*, 74, 33-47.

EWG, 1997, *Joint U.S.-Russian Atlas of the Arctic Ocean, Oceanography Atlas for the Winter Period*, NODC, CD-ROM available from NODC.

EWG, 1998, *Joint U.S.-Russian Atlas of the Arctic Ocean, Oceanography Atlas for the SummerPeriod*, NODC, CD-ROM available from NODC.

Martin, S. E., E. Munoz, and R. Dreucker, 1997, Recent observations of a spring-summer warming over the Arctic Ocean, *Geophys. Res. Lett.*, 24(10), 1259-1262.

Maslanik, J. A., M. C. Serreze, and R. G. Barry, 1996, Recent decreases in Arctic summer ice cover and linkages to atmospheric circulation anomalies, *Geophys. Res. Lett*., 23, 13, 1677-1680.

Thompson, W. J. and J. W. Wallace, 1998, The Arctic Oscillation signature in the wintertime geopotential height and temperature fields, *Geophys. Res. Lett.*, 25, 1297-1300.

Walsh, J. E., W. L. Chapman, and T. L. Shy, 1996, Recent decrease of sea level pressure in the central Arctic. *Journal of Climate* , 9, 480-486.

PUBLICATIONS

McPhee, M. G., T. P. Stanton, J. H. Morison, and D. G. Martinson, 1998, Freshening of the Upper Ocean in the Central Arctic: Is Perennial Sea Ice Disappearing?, *Geophys. Res. Lett.*, 25, 10, 1729-1732.

Morison, J. H., K. Aagaard, M. Steele, The Arctic Change: A Review, to be submitted to *Arctic* as part of a copendium of papers presented at the Arctic Seas Currents of Change Symposium in Mystic, Conneticut, October, 1998.

Serreze, M. C., J. E. Walsh, F. S. Chapin III, T. Osterkamp, M. Dyurgerov, V. Romanovsky, W. C. Oechel, J. Morison, T. Zhang and R. G. Barry, 1998, Observational evidence of recent change in the northern high-latitude environment, *Climatic Change* (accepted with revision 1998).

Morison, J. H., M. G. McPhee, 1998, Lead convection measured with an autonomous underwater vehicle, *J. Geophys. Res.I*, 45, 15-38, 103, C2, 3257-3281, (in press at time of last report).

Morison, J. H., M. Steele, R. Andersen, 1998, Hydrography of the upper Arctic Ocean measured from the nuclear submarine *USS Pargo*, *Deep Sea Research*,(in press at time of last report).

Smith, D.C., and J.H. Morison, 1998, Nonhydrostatic haline convection under leads in sea ice, *J. Geophys. Res.*, 103, C2, 3233-3247, (in press at time of last report).